

# Fescues with Large Roots are Drought Tolerant

## H.A. Torbert

Department of Agronomy and Soils  
Alabama Agriculture Experiment  
Station  
Auburn University  
Auburn, AL

## J.H. Edwards

USDA-ARS  
National Soil Dynamics Laboratory  
Auburn, AL

## J.F. Pedersen

USDA-ARS  
Department of Agronomy  
University of Nebraska  
Lincoln, NE

**Abstract.** Consideration of root/soil interactions is essential in adapting tall fescue (*Festuca arundinacea* Schreb.) to soil and climatic condi-

tions of the Coastal Plain region of the southeast. Sandy soils of the region are very susceptible to the formation of hardpans. These compacted layers often restrict plant root development to the plow layer (0 to 6 in.) and prevent plant roots from reaching available moisture and nutrients in the subsoil horizons. Plants grown under these conditions are shallow rooted and will be subjected to water stress up to 50% of the time during the growing season. Although implements are available to penetrate the hardpan, they have high energy requirements and provide temporary remedies. The limitation of root growth due to compaction layers has been cited as a causal factor of drought stress and resulting stand decline of tall fescue in the southeast. Research was initiated to determine the differences in soil water extraction of four fescue lines with different

root characteristics and "Kentucky 31" (KY-31) fescue used as a check. The fescues were grown on a sandy loam Coastal Plain soil with a known compacted zone at a depth of 0.4 to 0.6 m (16 to 24 in.). Two fescue lines with large diameter roots (LDR) in the range of 0.92 to 1.03  $\mu\text{m}$  and xylem diameters of 0.16 to 0.19  $\mu\text{m}$  penetrated the hardpan and extracted soil water to a depth of 48 in. In two fescue lines with small diameter roots (SDR) less than 0.9  $\mu\text{m}$  soil water extraction was restricted to the soil volume above 0.6 m. The increase in soil water removed from depths greater than 0.6 m was reflected in a 40% increase in dry matter yield for the LDR lines as compared to the SDR fescue lines. The LDR fescue lines offer genetic germplasm to be incorporated into a breeding program to improve drought tolerance of fescue in the southeast.

## Introduction

Tall fescue (*Festuca arundinacea* Schreb.) is an excellent cool season perennial forage grown on an estimated 35 million acres throughout much of the United States. The reasons for its popularity are: (1) wide range of adaptation, (2) persistence under a wide range of management regimes, (3) good forage yield, (4) a long growing season, and (5) excellent seed production. But tall fescue usually does not persist for more than three years in pastures in the Coastal Plain region of the southeastern USA (McCloud and Bula, 1985). However, old stands of tall fescue can be readily observed growing in water-rich environments such as low-lying areas of pastures and ditch banks in this region (Edwards and Pedersen, 1985). Therefore, it was assumed that soil water availability and rainfall distribution during the critical growth periods were significant factors restricting tall fescue persistence.

Most of the soils of the southern Coastal Plain are coarse-textured, loamy sands with sandy loam surface horizons that make them susceptible to compaction. The compaction zones, genetic or man-made, often result in shallow-rooted plants. A compacted layer below the Ap horizon can restrict root development and prevent plant roots from reaching available subsoil water and nutrients (Trowse and Musick, 1961; Taylor et al., 1964; Trowse and Baver, 1965; Lund and Elkins, 1978; Elkins et al., 1983).

Typically, a sandy soil of the Coastal Plain will have approximately .025 m (1 in.) of available water per 0.3 m (1 ft) of soil. If roots penetrate deeper than 0.15 m (6 in.) and evapotranspiration for the crop is 0.5 cm/day (0.2 in./day), the crop will have a 3-day supply of water. However, if rooting is extended to 0.3 m, the crop will have a 6-day supply of water. Data from long-term weather records in Alabama suggest that a summer crop with a rooting depth of 0.3 m will experience 42 days of water stress during May through July, 5 out of 10 years (Ward et al., 1959).

A potential solution to drought stress in tall fescue in the Coastal Plain region is the identification

*Address reprint requests to:* J.H. Edwards, USDA-ARS, National Soil Dynamics Laboratory, P.O. Box 792, Auburn, AL 36831-0792, USA.

and utilization of tall fescue lines with superior root characteristics that improve water absorption. This solution has been used successfully with other grasses. Increased xylem diameter was advantageous in wheat (*Triticum aestivum* L.) grown on stored soil moisture for the entire growing season (Passioura, 1972; Richards and Passioura, 1981a; Richards and Passioura, 1981b). An increase in hydraulic resistance in wheat root systems limited water uptake over the growing season, allowing for adequate soil moisture at critical periods of growth and development. Wheat plants with smaller xylem diameters have greater hydraulic resistance than those with larger diameters.

Tall fescue clones with large diameter roots (LDR) were less water-efficient than clones with small diameter roots (SDR) in greenhouse pot studies (Elkins et al., 1977). In addition, the same LDR clones were more susceptible than SDR clones to nematode damage in the greenhouse (Elkins et al., 1979). However, in the field where hardpans were present, LDR clones of tall fescue had superior drought resistance, persistence, forage yield, and sward cover (Williams et al., 1983).

The improved performance of LDR fescue clones under field conditions compared to SDR clones was associated with differences in root morphology of clones. However, the effects of tall fescue root morphology on water absorption from different soil depths had not been established. Thus, the objective of this study was to determine relative water removal from varying soil depths for tall fescue clones with differing root morphology.

## Materials and Methods

### Growth and Establishment

The tall fescue clones used in this experiment have been previously characterized for root diameter, xylem diameter, root cross-sectional area, and xylem cross-sectional area (Torbert, et al., 1985) and are shown in Table 1. Vegetative propagules of the four tall fescue clones, and 'Kentucky 31' (Ky-31) seedlings used as a check, were transplanted into 0.6 × 1.5 m (2 ft × 5 ft) plots on 1.5 m centers in Oct, 1981. The soil was a Cahaba fine sandy loam (fine-loamy, siliceous, thermic Typic Hapludult) with a compacted zone present at 0.25 to 0.35 m (8 to 14 in.). Soil pH averaged 5.6 for the top 0.6 m and 5.9 for the 0.6–1.2 m depth. The experimental design was a randomized complete block with three replications. The plots were maintained weed free by hand-pulling weeds throughout the study. Fertilizer was applied according to soil test recommendations to maintain all nutrients in high fertility levels. Annual application of 167 kg/ha (150

**Table 1.** Root morphological characteristics of tall rescue clones

Fescue clones	Average root diameter (mm)	Root diameter range (mm)	Xylem diameter (mm)	Root X-area <sup>a</sup> (mm <sup>2</sup> )	Xylem X-area <sup>a</sup> (mm <sup>2</sup> )
LDR <sup>b</sup>	0.90a <sup>c</sup>	0.76–1.04	0.17a	0.69a	0.03a
SDR <sup>b</sup>	0.68b	0.68–0.77	0.14b	0.43b	0.02b
KY-31	0.69b	0.61–0.73	0.11c	0.40c	0.013c

<sup>a</sup> X-area = cross-sectional area.

<sup>b</sup> LDR = large diameter roots; SDR = small diameter roots.

<sup>c</sup> Means with the same letter are not significantly different at the 5% level of probability.

lbs/A) of 0–8.8–16.6 was applied each year in August. In Dec 1983, 111 kg/ha N as NH<sub>4</sub>NO<sub>3</sub> was applied, and 67 kg/ha N was applied after each harvest. The plots were allowed to grow for 1.5 years prior to collecting data to allow them to approximate a mature tall fescue sward.

Forage was harvested by hand cutting 7 April and 9 May, 1984. Yield was determined on a dry wt/area basis and two cuttings were combined to calculate total yield for the year. The yields were statistically tested for significant difference using LSD test.

Ten propagules of each fescue clone were grown in 12-L (4 gallons) tanks in the greenhouse. Each propagule was replicated 10 times and 20 random roots were selected from each propagule to determine root characterization. All root diameters were measured within 4 hours of removal from the fescue lines. A cross-sectional slice of each root, taken 7.5 cm from the root apex, was examined under a microscope. A scaled eyepiece was used to measure root and xylem diameters (Torbert et al., 1985).

### Soil Water Content

Soil water determinations were initiated 4 May, 1983 and were made three times weekly until 31 December, 1984. Soil water measurements were made with neutron probe and tensiometers at 0.2, 0.6, and 1.0 m. In 1984, additional neutron probe measurements were made at 0.4, 0.8, and 1.2 m soil depths.

The neutron probe contained a built-in factory calibration curve to convert the number of measured slow neutrons to volumetric water content or theta (θ). The probe was also calibrated for the Cahaba fine sandy loam soil by taking readings on an area adjacent to the plots and then determining the water content from samples taken at the same time. The following equation converted the θ<sub>r</sub> (water content in percent moisture) to the true θ, θ<sub>s</sub> (water content as a fraction):

$$\theta_s = (1.2632 + (\theta_r * 0.08062)) / 100 \quad (1)$$

The amount of water present in the soil profile (AMW) was calculated for 1984 by using neutron probe readings at consecutive depths in a trapezoidal area equation:

$$AMW = E_i 0.5(\theta_i + \theta_{i+1}) \quad (2)$$

$$\theta_i = 1 - 6$$

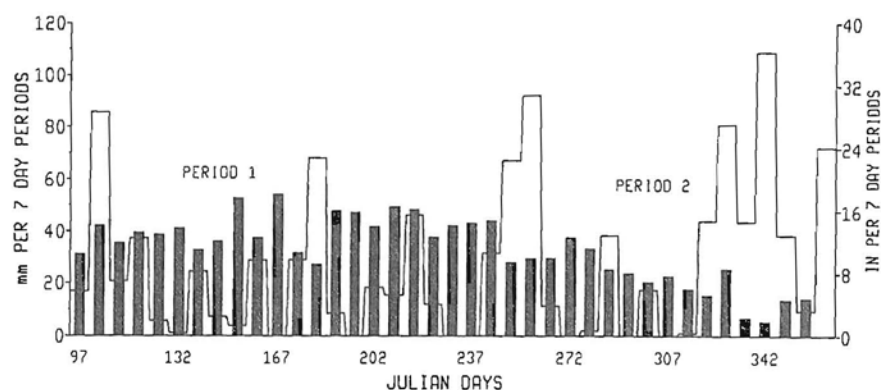


Fig. 1. Rainfall (□) and pan evaporation (■) mm per week at the Plant Breeding Substation for 1983 for the fescue growing season.

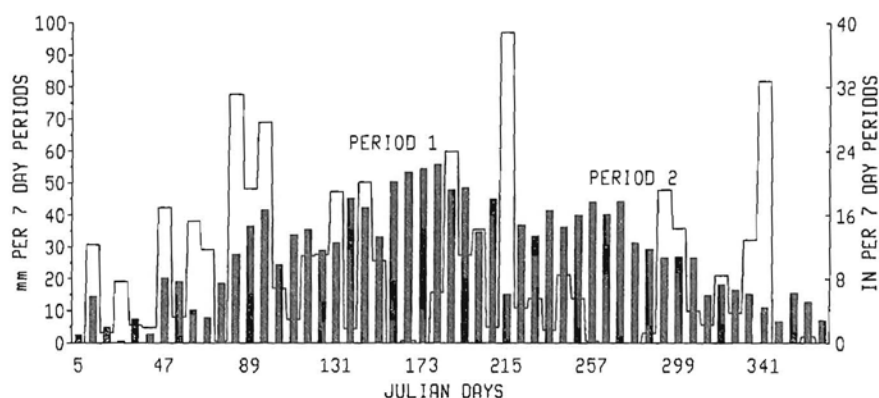


Fig. 2. Rainfall (□) and pan evaporation (■) mm per week at the Plant Breeding Substation for 1984 for the fescue growing season.

Table 2. Forage yield for the tall fescue clones

Fescue clones	Harvest 1 (g/m <sup>2</sup> )	Harvest 2 (g/m <sup>2</sup> )	Total (g/m <sup>2</sup> ) <sup>c</sup>
Ky-31	736a <sup>a</sup>	471a	1207a
LDR <sup>b</sup>	565a	452a	1017a
SDR <sup>b</sup>	380b	346b	726b

<sup>a</sup> Means with the same letter are not significantly different at the 5% probability level using LSD.

<sup>b</sup> LDR = large diameter root; SDR = small diameter root.

<sup>c</sup> For conversion to lb/ac multiply by 8.88.

where ( $i = 2-7$ ) is the volumetric water content taken at depths of 0.2, 0.4, 0.6, 0.8, 1.0, and 1.2 m,  $\theta_i$  is the water content of the soil surface determined by extrapolation of water content values at the lower depths. Sufficient irrigation was applied to the plots to saturate the profile on 13 May and 29 Oct, 1983.

### Soil Water Tension

Tensiometers were used to measure soil water tension ( $\psi_p$ ). Each tensiometer was calibrated for zero tension and checked to maintain a 55 kPa tension (0.55 bar). The

55 kPa tension was taken to be the maximum tension for the tensiometers.

### Weather Data

Rainfall was measured at the experimental site and recorded daily. Other climatological data such as relative humidity, daily pan evaporation, daily rainfall, and daily temperature were collected from the closest official weather station that was located within 25 miles of the experimental site.

## Results

### Forage Yield

The LDR fescue clones had a 33% higher dry matter production at the first harvest and 24% higher yield at the second harvest than SDR clones (Table 2). Ky-31 had 48% and 27% higher yields than the SDR clones for the first and second harvests. Total forage yield for the year was 29% higher for LDR clones and 40% higher for Ky-31

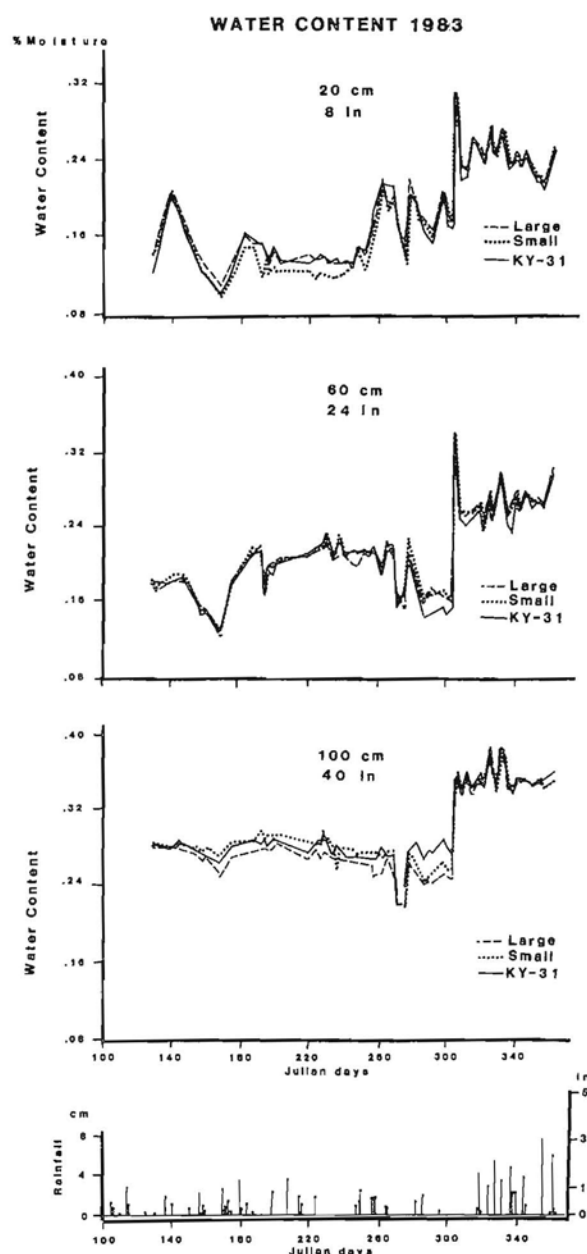


Fig. 3. Volumetric water content ( $\theta$ ) and rainfall for LDR, SDR, and KY-31 at 0.2 (8), 0.6 (24), and 1.0 m (40 in.) depths for 1983.

than for SDR clones. Pan evaporation and rainfall data from the official weather station (Figs. 1 and 2) indicates that evaporation exceeded rainfall 70 to 80% of the time the tall fescue clones were actively growing in the spring and fall of both years. The water used during these periods of reduced rainfall was from stored subsoil water.

## Soil Water Content

The change in volumetric soil water content ( $\theta$ ) is shown in Figures 3 and 4. In 1983, during the period 190–240 days, soil water content at 0.2 m (8 in.) was 11.7% higher for LDR clones than for SDR clones (Fig. 3). At 0.6 m, soil water content did not vary among tall fescue clones. At 1.0 m, LDR clones generally had 5% lower soil water content than SDR clones through day 300. Soil water content under Ky-31 plants was intermediate between that of LDR and SDR clones at 1.0 m.

In 1984, LDR and SDR clones showed similar patterns of soil water removal, except during the driest periods of the year (Fig. 4). During two dry-down periods, 150–208 and 220–330 days, SDR clones had lower soil water content at 0.2 m than LDR clones. However, soil water content was lower in LDR clones than in SDR clones at 0.8, 1.0, and 1.2 m. The soil profile was assumed to be saturated prior to these dry-down periods due to frequent heavy rainfall.

The amount of water removed from each soil depth in the profile during the period 155–165 days in 1984 (rapid dry-down period) is shown in Table 3. LDR clones removed 23% more total soil water than SDR clones from days 151 to 170. Sixty-nine percent of the water removed by SDR clones was from the upper 0.6 m of soil during this same time period. LDR clones removed soil water more evenly throughout the profile with 36% of the water removed from areas below 0.6 m. During a period of reduced water stress (275–282 days), SDR clones removed 31% less water than did LDR clones.

Table 3. Water removed by fescue clones from a soil profile during two dry-down cycles in 1984 (days 151–170 and 275–282)

AND 275-282							
	Depth, m (in.)						
	0.2	0.4	0.6	0.8	1.0	1.2	Total
Fescue clones	(8)	(16)	(24)	(32)	(40)	(48)	
	(mm of water removed)						
days 151-170							
LDR <sup>a</sup>	11.8	8.1	7.6	7.0	5.3	3.4	43.3
SDR <sup>a</sup>	10.5	7.5	7.4	5.7	1.8	0.5	33.3
days 275-282							
LDR	0.7	2.2	5.8	6.8	3.4	2.4	21.3
SDR	1.3	1.7	5.2	5.3	1.4	0.5	15.4

<sup>a</sup> LDR = large diameter roots; SDR = small diameter roots.

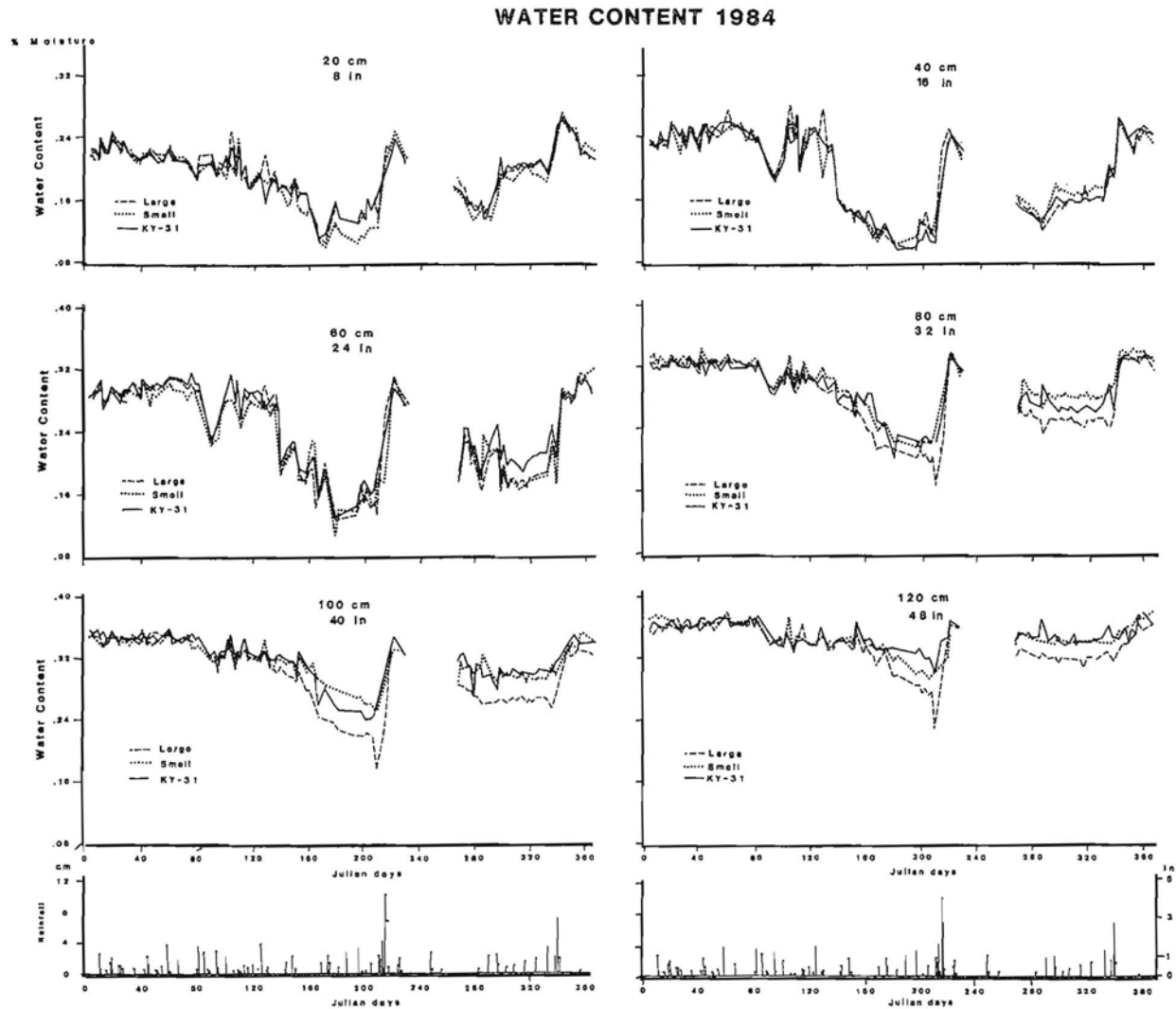


Fig. 4. Volumetric water content ( $\theta$ ) and rainfall for LDR, SDR, and KY-31 at 0.2 (8), 0.4 (16), 0.6 (24), 0.8 (32), 1.0 (40), and 1.2 m (48 in.) depths for 1984.

### Soil Water Tension

The soil water tension at 0.2 m was affected more by frequency of rainfall than by fescue clones (Fig. 5). In 1983, at depths greater than 0.6 m (24 in.) between 180–250 days, LDR clones had 20 to 51% higher soil water tension than SDR clones. In 1984, during two periods of drought stress between days 120–160 and 220–260 (Fig. 6), soil water tension was higher in SDR clones at 0.2 m. At 1.0 m, LDR clones had soil water tension ranging from 18 to 50% higher than SDR clones.

### Discussion

Roots growing through soil will extract water from the top of the profile, and then from greater depths as the soil dries out, until the soil becomes too dry to support growth (Davis, 1941; Russell, 1977; Weatherly and Dane, 1979). Water will also move up in a soil profile in response to an actively growing root system (Van Bavel et al., 1968; LaRue et al., 1968; Stone et al., 1973). However, Weatherly and Dane (1979) found little water movement between soil depths during dry periods of the

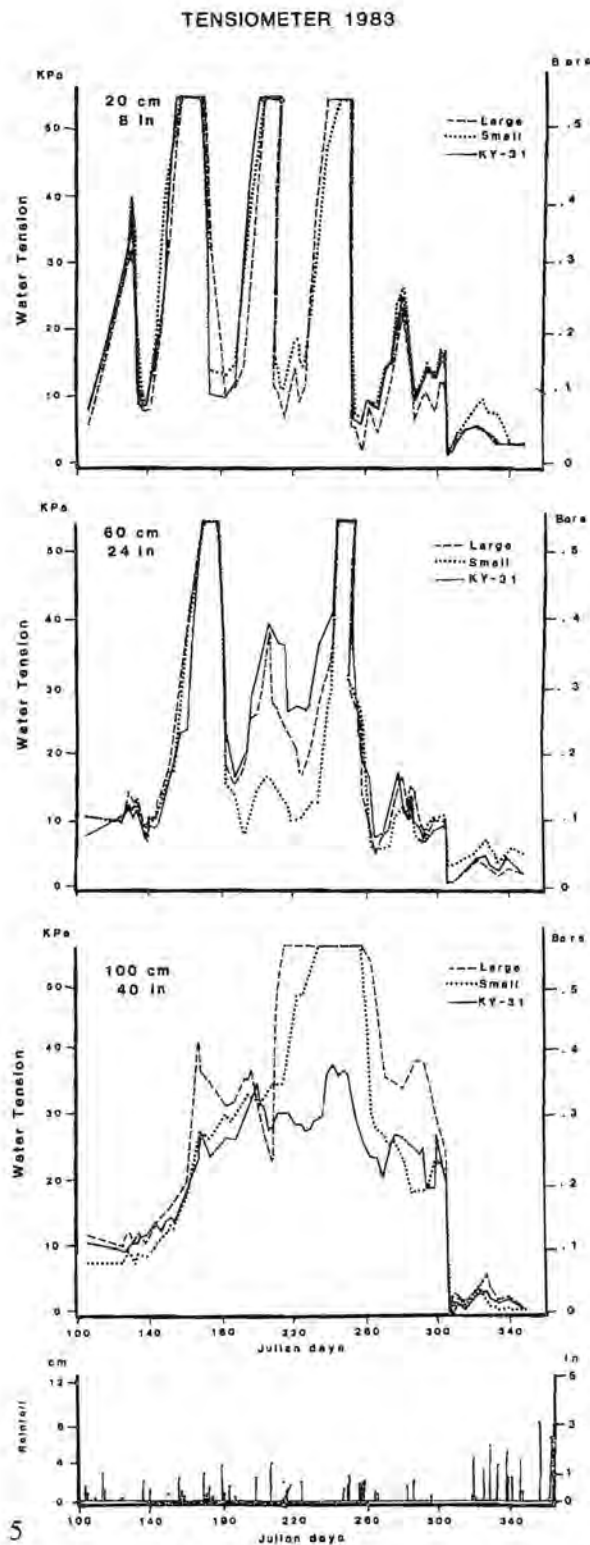
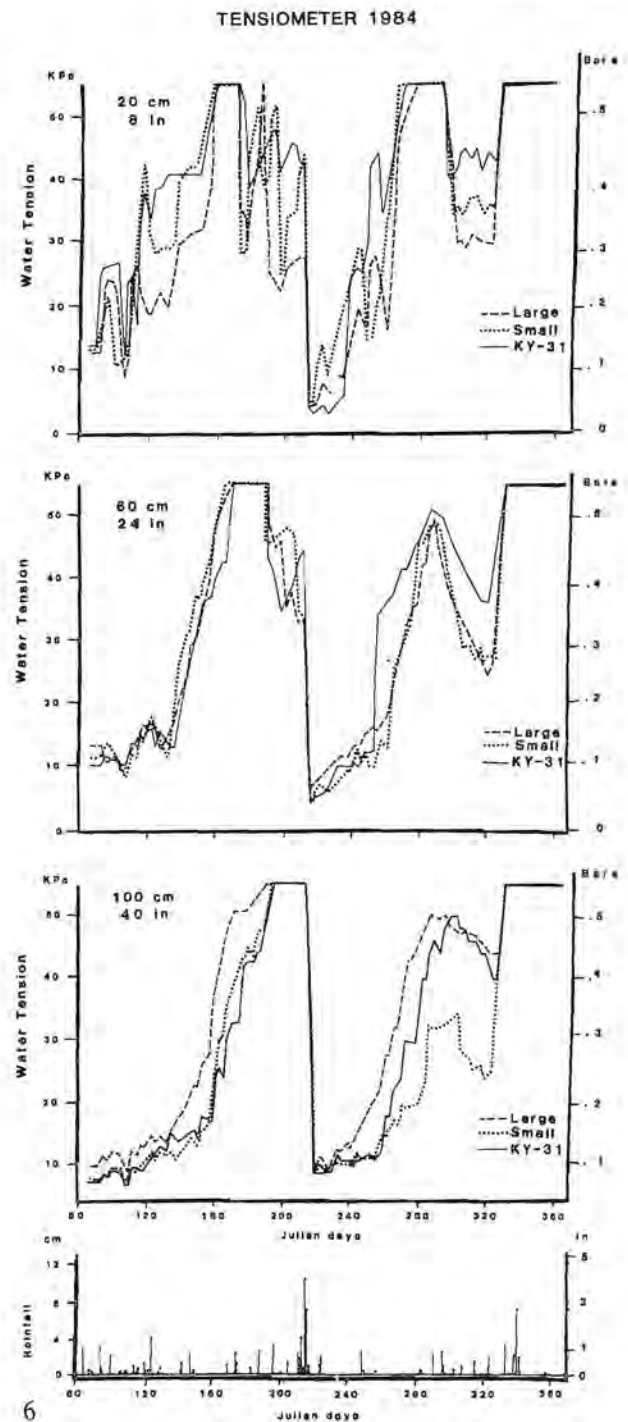


Fig. 5. Soil water tension and rainfall for LDR, SDR, and KY-31 at 0.2 (8), 0.6 (24), and 1.0 m (40 in.) depths for 1983.

Fig. 6. Soil water tension and rainfall for LDR, SDR, and KY-31 at 0.2 (8), 0.6 (24), and 1.0 m (40 in.) depths for 1984.

growing season at a test site with similar soils located less than 10 km (6.2 miles) from our study.



Therefore, differences seen in the soil moisture conditions under the tall fescue clones were assumed to be due to differential water uptake by LDR and SDR fescue clones.

Soil water removal under the tall fescue clones over a period of time followed the same trends as documented for other plants with actively growing roots. The soil dried out first in the top layers and then became drier at greater depths as the period of



reduced rainfall persisted. The increase in water removed from soil depths greater than 0.6 m by LDR clones (Table 3) suggested that the roots were active at these depths. During these dry periods, pan evaporation exceeded rainfall (Fig. 3).

Root observations from soil pits (Williams et al., 1981) showed the LDR roots were growing to a depth of 1 m (40 in.). Roots of the SDR fescue lines were restricted to the soil volume above the tillage pan. The restricted layer was located at a depth of 25 to 35 cm. At our experimental site, the restricted layer was located from 0.4 to 0.8 m below the surface. Thus, the increased water removal that occurred at depths greater than 0.6 m (24 in.) with LDR lines was associated with increased rooting depth.

## Conclusion

One of the challenges to plant breeder and agronomist is to identify genetic material that can tolerate extremes in soil and climatic conditions of the Coastal Plain region. The limitation of root growth due to soil compaction in these sandy soils is a causal factor of drought stress in this region and a major factor in lost yield potential. However, the selection of tall fescue lines with superior root characteristics may be a means for adapting tall fescue to an area that is in need of a high-yielding perennial grass. The ability of LDR clones to access deep soil water during periods of drought should provide a mechanism for drought-resistance in tall fescue. Breeding efforts are underway to develop new tall fescue varieties with enhanced drought resistance through LDR's. Such varieties would be very important in areas such as the Atlantic Coastal Plain.

## References

- Davis, C.H. 1941. Absorption of soil moisture by maize roots. *Bot. Gaz.* 101:791-805.
- Edwards, J.H., and J.F. Pedersen. 1985. Why won't tall fescue grow in the Coastal Plains region of the Southeast? p. 129-136. *In* 1985 Forage and Grassland Conference. Proc. 1985 Amer. Forage and Grassland Conf., Hershey, PA. 3-6 March 1985. American Forage and Grassland Council. Lexington, KY.
- Elkins, C.B., R.L. Haaland, and C.S. Hoveland. 1977. Grass roots as a tool for penetrating soil hardpans and increasing yields. p. 21-26. *In* Proc. 34th Southern Pasture and Forage Improvement Conference, Auburn University, Auburn, AL. April 12-14, 1977.
- Elkins, C.B., R.L. Haaland, R. Rodriguez-Kabana, and C.S. Hoveland. 1979. Plant parasitic nematode effects on water use and nutrient uptake of a small- and large-rooted tall fescue genotype. *Agron. J.* 71:497-500.
- Elkins, C.B., D.L. Thurlow, and J.G. Hendrick. 1983. Conservation tillage for long term amelioration of plow pan soils. *J. Soil Water Conserv.* 38:305-307.
- LaRue, M.E., D.R. Nielsen, and R.M. Hagan. 1968. Soil water flux below a ryegrass root zone. *Agron. J.* 60:625-629.
- Lund, Z.F., and C.B. Elkins. 1978. Creating soil conditions favorable to root growth. *In* 1978 Beltwide Cotton Production Mechanization Conference Proceedings, Dallas, TX. Jan 9-12, 1978.
- McCloud, D.E., and R.J. Bula. 1985. Climatic factors in forage production. p. 33-42. *In* M.E. Heath et al., (eds.) Forages, the science of grassland agriculture. 4th edition. The Iowa State University Press, Ames, Iowa.
- Passioura, J.B. 1972. The effect of root geometry on the yield of wheat growing on stored water. *Aust. J. Agric. Res.* 23:745-752.
- Richards, R.A., and J.B. Passioura. 1981a. Seminal root morphology and water use of wheat: I. Environmental effects. *Crop Sci.* 21:249-252.
- Richards, R.A., and J.B. Passioura. 1981b. Seminal root morphology and water use of wheat: II. Genetic variation. *Crop Sci.* 21:253-255.
- Russell, R.S. 1977. The water relations of plant root systems. p. 90-110. *In* Plant root systems: their function and interaction with the soil. McGraw-Hill Book Co., Maidenhead, Berkshire, England.
- Stone, L.R., M.L. Horton, and T.C. Olson. 1973. Water loss from an irrigated sorghum field: I. Water flux within and below the root zone. *Agron. J.* 65:492-495.
- Taylor, H.M., L.F. Locke, and J.E. Box. 1964. Pans in Southern Great Plains soils: III. Their effects on yield of cotton and grain sorghum. *Agron. J.* 56:542-545.
- Torbert, H.A., J.H. Edwards, and J.F. Pedersen. 1985. Growth and magnesium uptake of tall fescue clones with varying root diameters. *J. Plant Nutrition* 8:731-749.
- Trouse, A.C., Jr., and L.D. Baver. 1965. Tillage problems in the Hawaiian sugar industry. III. Vehicle traffic and soil compaction. Tech. Suppl. to Soil Rpt. No. II, Exp. Stn. Hawaiian Sugar Planters' Assn.
- Trouse, A.C. and J.T. Musick. 1961. Some effects of soil compaction on the development of sugar cane roots. *Soil Sci.* 91:208-217.
- Van Bavel, C.H.M., G.B. Stark, and K.J. Burst. 1968. Hydraulic properties of a clay loam soil and the field measurement of water uptake by roots: II. The water balance of the root zone. *Soil Sci. Soc. Am. J.* 32:317-321.
- Weatherly, A.B., and J.H. Dane. 1979. Effect of tillage on soil-water movement during corn growth. *Soil Sci. Soc. Am. J.* 43:1222-1225.
- Ward, H.S., C.H.M. van Bavel, J.T. Cope, L.M. Ware, and H. Bouwer. 1959. Agricultural drought in Alabama. Al. Polytechnic Inst. Agr. Exp. Sta. Bull. 316.
- Williams, C.B., C.B. Elkins, R.L. Haaland, C.S. Hoveland, and R. Rodriguez-Kabana. 1983. Effects of root diameter, nematodes, and soil compaction on forage yield of two tall fescue genotypes. p. 121-124. *In* Proceedings XIV International Grassland Conference, Lexington, KY. June 15-24, 1981. Westview Press, Boulder, CO.